

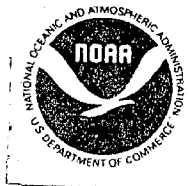
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**CATASTROPHIC MORTALITY OF THE SEAGRASS Thalassia testudinum
IN FLORIDA BAY**

ANNUAL COMPLETION REPORT TO OFFICE OF COASTAL ZONE MANAGEMENT

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SCOPE OF WORK

In a previous CZM-funded study, our research focused on Thalassia morphometrics, productivity, and stress physiology as part of a collaborative die-back research group including investigators from FMRI, Everglades Park, University of Georgia, University of Virginia, and FIU. In this study we continued some of the previously described sampling and initiated new studies which centered on seagrass community dynamics at the basin level and initiated more extensive experimental studies on causal mechanisms. The data from these studies have already been valuable to researchers who are now studying effects of the die-back on invertebrates and fish species in Florida Bay. We continued with our use of Sunset Cove, Rankin Lake, Johnson Key Basin, and Rabbit Key Basin as primary sampling sites based on our previous study results.

TASK 1 CHARACTERIZATION OF DIE-BACK SPREAD AND RECOVERY RATES.

SUBTASK 1.1. Dieback patch mapping.

METHODS

Die-back mapping patches were established in Sunset Cove, Rankin Lake, and Johnson and Rabbit Key Basins. A permanent central stake or anchor was established in the approximate center of either the open die-back area or where die-back was extensive (e.g., Rankin Lake and Sunset Cove), within a small Thalassia patch. Distances from the reference stake to the ecotone of the patch were measured at 30° intervals during each bimonthly sampling. Patch area was estimated by calculating the area of the triangle formed by the individual 30° segments and calculating the sum of the 12 segments.

During the initial establishment of the Johnson Key basin and Sunset Cove map sites, PVC stakes were placed at the ecotone at the cardinal compass points and these stakes were used as reference points for paired fixed-frame photoquad sampling (focal length four feet, sampling area ca. 625 cm²). These sites were photographed approximately bimonthly from March 1989 to October 1991. The resulting slides were projected onto a 10 row x 15 column grid and the number of grid points contacting Thalassia were counted as an estimate of coverage.

RESULTS AND DISCUSSION

The amount of regrowth and resulting 'fingers' of Thalassia in the original die-back map patch in Johnson Key (Figure 1) made determination of the ecotone impossible. Therefore, two new map patches were established in this basin. New map patches were also established in Rabbit Key basin and in Rankin Lake. Unfortunately, the floats marking the two patches in Rankin Lake

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disappeared after the second set of measurements were taken and the sites could not be relocated. The two new Johnson Key basin die-back patches and the new Rabbit Key basin die-back patch exhibited an overall recovery trend during this study (Figure 2). The JKA patch did show a slight increase in area between the June and August sampling periods which corresponds to the period in which a major die-back event was observed in this basin. All three patches exhibited relatively rapid regrowth between August and October. In contrast, the Sunset Cove Thalassia patch exhibited rapid spread between June and August and a possible loss in area between August and October (Figure 3). The reasons for this difference in growth patterns is unknown, but it may reflect some basic distinctions between the seasonality of Thalassia growth at western and eastern Florida Bay sites.

Photoquad data for the original Johnson Key and Sunset Cove map patches also indicates differences in seasonal regrowth patterns although both sites exhibited an overall recovery trend over the 32 month study period (Figure 4). The Johnson Key basin patch exhibited loss of Thalassia between December 1989 and February 1990, and between June 1990 and August 1990. Sunset Cove exhibited little or no regrowth of Thalassia between April and June of 1989 and a slight loss between September 1990 and February 1991. This latter period corresponds to the time of year that the die-back was first observed in Sunset Cove (i.e., January and February of 1989).

SUBTASK 1.2. Measure spread and recovery of die-back patches in permanent quadrats.

METHODS

Because of the initiation of a standardized vegetational monitoring program (> 50 - 25 x 25 m permanent quadrats throughout Florida Bay) by ENP research personnel, the focus of this subtask was altered to assess, on a basin level, the frequency, abundance and relative density of the major plant species/groups in Rankin Lake, Johnson Key Basin and Rabbit Key Basin. This was accomplished using the Braun-Blanquet cover-abundance scale (Mueller-Dombois and Ellenberg, 1974). This scale uses absolute values to provide species- or plant group-specific quantitative information requiring little time per sample area, thus allowing a larger area to be effectively sampled.

In each basin, 10 sample sites were randomly selected from a 0.5 km sample-point grid. At each sample site, four 0.25 m² quadrats (thrown north, east, south and west of a reference point) were sampled for species occurrence and quantity (40 quads/basin) using the following scale: 5-any number of individuals with > 75% cover, 4-any number of individuals with 50-75% cover, 3-any number of individuals with 25-50% cover, 2-any number of individuals with 5-25% cover, 1-plentiful, but less than 5% cover, 0.5-sparse, with small cover. Using this scale,

the frequency of occurrence (# of quads where a species was observed/total # of quads), abundance (sum of cover-abundance scale values/# of occupied quadrats) and relative density (sum of cover-abundance scale values/total # of quadrats) of each seagrass species and the dominant algal species or groups were calculated. Braun-Blanquet sampling was initiated in February and continued on a bimonthly basis to October.

RESULTS AND DISCUSSION

The results of each bimonthly sampling are presented in Figures 5-9. It is readily apparent from these figures that each basin has distinctive floral characteristics with Rankin Lake being especially distinct from Johnson and Rabbit Key basins. Throughout the year, Rankin Lake was dominated by Halodule and Batophora, while Thalassia was dominant in Johnson Key and Rabbit Key basins. The latter two basins also consistently had a higher algal species diversities than Rankin Lake. Syringodium was consistently observed in Johnson Key quadrats throughout the year at a lower frequency than Halodule, but it had higher abundances than Halodule during the February, April and June samplings. This pattern reflects the patchy distribution of Syringodium in Johnson Key Basin, but indicates that it grows to relatively high densities where it occurs. Syringodium was only detected during the April and August samplings in Rabbit Key Basin. This was due to its patchy occurrence in this basin (we've only observed Syringodium in the extreme western portion of the basin) rather than to seasonal variability. Syringodium was not observed in Rankin Lake. In contrast, Ruppia was only observed in Rankin Lake and was only detected in the sampling quadrats during June and August. The low frequency, abundance and density of Ruppia reflect its patchy and sparse growth habit. Ruppia exhibits pronounced seasonality in its growth, producing abundant (and easily observable) festoon-like stems from March through August. These reproductive stems break off during the fall and winter and Ruppia becomes virtually indistinguishable from Halodule, where they grow intermixed.

Figure 10 summarizes the changes in frequency, abundance and density of the two dominant seagrass species (Thalassia and Halodule) within the three basins sampled during this study. In Rankin Lake, which has experienced the most severe die-back, Thalassia frequency exhibited a decline while its abundance and density were relatively unchanged. This indicates that Thalassia distribution is becoming more patchy within this basin and may also suggest that Thalassia is continuing to decline through the loss or reduction in size of surviving patches rather than through a gradual reduction in short-shoot densities (i.e. stand thinning). In contrast, the frequency of occurrence of Halodule in Rankin Lake increased from 78% during reproductive sampling in September 1990 to consistently approaching or equaling 100%, indicating a uniform basin wide distribution of this species. Both abundance and density increased during the study period reflecting continuing colonization and growth of Halodule within

this basin.

In Johnson Key Basin, Thalassia exhibited a decline in frequency of occurrence from June to October (Figure 10). This corresponded to the period in which a major die-back event was observed by ENP research personnel. This die-back was initiated during mid-June. Abundance and density of Thalassia in Johnson Key Basin declined throughout the study, but the most dramatic decline occurred between August and October. The frequency of Halodule also declined in Johnson Key Basin during the study indicating the distribution of this species became more patchy and may have been affected by the die-back event. Both Thalassia and Halodule populations remained relatively stable throughout the study within Rabbit Key Basin. If anything, Thalassia abundance and density seemed to increase over time with little change in these parameters for Halodule. Frequency of occurrence of Halodule in Rabbit Key Basin increased from February to October.

SUBTASK 1.3 Determination of flowering short-shoot and seedling densities.

METHODS

During the bimonthly Braun-Blanquet frequency/abundance survey in April, the numbers and sex of flowering short-shoots of Thalassia occurring within sample quadrats were recorded. Four replicate 0.25 m² quadrats in each of ten randomly selected sample sites in Rankin Lake, Johnson Key and Rabbit Key Basins were surveyed. During the June and August surveys, the occurrence and numbers of fruits and/or seedlings were recorded.

RESULTS AND DISCUSSION

Similar to what was observed during the previous year (Carlson et al., 1990), the distribution of reproductive short-shoots was very patchy. Again, no flowering short-shoots were observed in Rankin Lake. Flowering was observed in 28% of the quadrats in Johnson Key Basin and in 15% of the quadrats in Rabbit Key Basin. Observed reproductive densities were higher in Johnson Key Basin compared to Rabbit Key Basin with 0.6 female and 0.8 male short-shoots m⁻² in the former basin and 0.3 female and 0.5 male short-shoots m⁻² in the latter. Both basins had male-biased sex ratios - male:female=1.3 in Johnson Key Basin and 1.7 in Rabbit Key Basin.

During the June sampling, Thalassia fruits were observed only in Rabbit Key Basin and they occurred in 10% of the quadrats. Fruit density was estimated to be 0.9 fruits m⁻² based on quadrat observations. The lack of observed fruit production in Johnson Key Basin may have been due to the high turbidity of the water in this basin during June, or could have reflected the occurrence of a widespread, recent die-off event during this period.

Seedlings of Thalassia were observed during the August sampling only in Rabbit Key Basin. This concurs with our fruit observations and suggests local recruitment rather than import from other basins. The absence of reproductive short-shoots in Rankin Lake for the past two years suggests that if recovery of Thalassia within this basin is to occur, it will have to be based on vegetative regrowth.

OVERALL CONCLUSIONS

The Braun-Blanquet data indicated that, at the basin level, there was relatively little or no net recolonization by Thalassia within Rankin Lake. Because no flowering short-shoots, fruits, or seedlings of Thalassia have been observed in either Rankin Lake or the adjacent north portion of Whipray Basin for the past two years, the only mechanism for recovery available to this species is recolonization by vegetative growth. However, regrowth of Thalassia has been outstripped by the rapid spread of Halodule as indicated by the increase in Halodule's frequency, abundance and density during the past year. The net effect of these species-specific differences in regrowth patterns is that Rankin Lake has been changed from a Thalassia-dominated system to a Halodule and Batophora-dominated system. This change in species dominance can be expected affect habitat function within the Lake (Zieman, 1982). Recolonization of previously barren die-back patches by Halodule seems to have had some beneficial effects - water clarity seemed much better than last year (not quantified) and blue-green algal mats were less common. We also observed, for the first time, the consistent presence of fishing activity within the Lake and we observed tarpon and dolphins feeding in the shallow flats adjacent to Rankin Key. While this information is anecdotal, it does suggest that the Rankin Lake system has become more ecologically stable.

In contrast, Johnson Key Basin experienced an overall loss of Thalassia and Halodule over the past year. This loss corresponds to the occurrence of an extensive die-back event which initiated during June. This die-back seemed to affect not only Thalassia, but may have led to a reduction (or at least an increase in patchiness) in Halodule as well. Map patch and photoquad data demonstrated that on a smaller scale, surviving plants were producing new short-shoots and that there was regrowth into existing die-back patches, so the basin-level patterns may be due to an increase in the number of new die-back patches. The difference in patterns determined using basin level versus die-back patch level sampling point out the value of a multi-level sampling strategy in assessing a phenomenon of this magnitude.

Rabbit Key Basin exhibited the most stability in seagrass species abundance patterns. The map patch data indicated regrowth of Thalassia into existing die-back patches. No additional basin wide decline of Thalassia was indicated during

the past year, but there was an increase in the frequency of occurrence of Halodule (>50% by October) indicating possible recolonization of previously unvegetated sites by this species.

The initiation of a major die-back event within Johnson Key Basin during a summer with relatively high rainfall (salinities were about 10 ‰ lower during the summer of 1991 than during the same periods in 1989 and 1990, see Figure 11) and during the period with longest day lengths raises questions regarding some of the previously suggested environmental/seasonal conditions (i.e. the warm water temperatures and decreasing daylength of fall) responsible for causing this die-back. Over the course of our studies, active seagrass die-back has been observed during summer and fall (western Florida Bay sites) and winter (Sunset Cove), and during both relatively dry and wet years. These observations suggest the possibility that die-back may be linked to characteristics of the particular seagrass population (i.e. the age or successional stage of the bed) rather than, or coupled with, external environmental factors.

TASK 2. ROLE OF SYNERGISTIC STRESS IN DIE-BACK AND RECOVERY OF Thalassia testudinum IN FLORIDA BAY.

The objective of this task was to determine the capacity of healthy and diseased Thalassia to avoid hypoxic stress and sulfide toxicity. Because previous CZM-funded research indicated that hypoxic stress and sulfide toxicity of Thalassia roots and rhizomes play important roles in the die-back process, we reasoned that any phenomenon which interfered with the ability of seagrasses to maintain aerobic conditions in their roots and rhizomes could contribute to die-back. Because previous studies also indicated that the pathogenic slime mold Labyrinthula plays a major role in the die-back process (Porter, 1989), we hypothesized that Labyrinthula may induce rhizome hypoxia and sulfide toxicity in Thalassia by 1) physically disrupting the oxygen-conducting system of the plant and/or 2) reducing the amount of photosynthetically-produced oxygen available for belowground tissue. Subtask 2.1 comprised field and lab experiments to determine the ability of healthy and diseased plants to supply oxygen to their belowground tissues. Subtask 2.2 involved a field experiment to test the effect of sediment sulfide and sediment-borne pathogens on seedling and rhizome transplant survival in die-back patches.

SUBTASK 2.1. Oxygen transport rates through healthy and diseased Thalassia shoots.

METHODS

Laboratory measurements of potential diffusive oxygen flux rates through intact plants were made using methane and ethane as conservative tracers. Thalassia plants collected from Tampa Bay and Florida Bay were incubated in gas-filled chambers to estimate diffusive resistances of different parts of the plant (ie.

leaves, stems, rhizomes, roots). *Thalassia* rhizomes with a healthy apex and at least three lateral (short) shoots were collected from Fort Desoto Park and Lassing Park in Tampa Bay. Healthy and diseased rhizomes from Florida Bay were collected from two of our previous study areas: Johnson Key Basin and Sunset Cove.

To estimate the flux of gas through the internal airspaces (aerenchyma) of *Thalassia testudinum*, we used the distal 20-30 cm rhizome segment with at least one short-shoot. We first cut each rhizome 1 cm behind the apex and again approximately 10 cm behind the first fully-expanded short shoot. Swagelok connectors and/or Tygon sleeves were used to connect Mylar bags to the cut ends of the rhizome. A cylindrical polyethylene chamber with a flexible gas reservoir was slipped over the short shoot and sealed at the base. Tracer (methane or ethane) was added to the short-shoot chamber, and accumulation of tracer was monitored in the Mylar bags enclosing the cut rhizome ends. The rhizome was wrapped with non-adhesive Teflon tape to impede radial loss of gases, but a gap in the tape was left at each rhizome end to prevent gas channeling.

Tracer concentrations in the source reservoir and Mylar bags enclosing the cut rhizome ends were measured on a Carle AGC-100 gas chromatograph. C_1 and C_2 hydrocarbon gases were separated on a 5' x 1/8" stainless steel column packed with Porapak Q and a 1' silica gel pre-column. The flame ionization detector response was calibrated with a standard hydrocarbon mixture (Scott Specialty Gases), and concentrations were estimated from peak areas measured by a SpectraPhysics SP4270 integrator.

Tracer concentrations in source and rhizome bags were determined every 10-30 minutes. Source bags were sampled using a 50 ul gas-tight syringe, while rhizome bags were sampled using a 500 ul gas-tight syringe. Over the course of a 3 to 6 hour flux experiment, a negligible volume of gas was removed from each bag.

After 5-8 data points were collected from the "whole-shoot" experiment, the upper portion of the short shoot was removed, and the resistance of the shoot base and rhizome were determined by attaching a new tracer and reservoir to the cut shoot base. Tracer flux through the shoot base and rhizome was measured for 2-4 hours before the shoot base was removed. Fluxes through the "mature" (proximal) and apical (distal) segments of the rhizome were then measured. Typical results for a series of flux measurements on two shoots are shown in Figure 12.

At the end of each experiment, leaf area, rhizome porosity, diffusion path length, and rhizome cross-sectional area were determined. Image analysis of aerenchyma area was attempted (Figure 13), but proved unsuccessful. Aerenchyma volume was determined gravimetrically by weighing a rhizome segment before and after flooding the internal air spaces with distilled water.

MODEL DEVELOPMENT

To describe gas transport in *Thalassia* rhizomes, we used a generalized version of Fick's first law:

$$F = K_L * (C_{Hi} - C_{Lo})$$

where F = flux in mol/cm²/s, K_L = the exchange coefficient in cm/s, C_{Hi} = the source concentration of tracer in mol/cm³, and C_{Lo} = tracer concentration at the cut rhizome ends (Boudreau and Guinasso, 1978). This equation applies to unidirectional flow and assumes K_L , C_{Hi} , and C_{Lo} are constant.

The exchange coefficient, K_L , in turn, is defined as the effective diffusion coefficient (D_s) divided by the diffusion path length (l) measured in cm:

$$K_L = D_s / l .$$

D_s is defined as follows:

$$D_s = D_o / 0^2$$

where D_o is the diffusion coefficient of the gas in air, and 0 is the tortuosity (Berner, 1980). Tortuosity, in this case, would be the actual distance travelled by a tracer molecule through a rhizome segment with length l . The effective rhizome cross-sectional area (aerenchyma area) was calculated by multiplying the total cross-sectional area by the rhizome porosity.

RESULTS AND DISCUSSION

A frequency plot of rhizome porosity is shown in Figure 14. Modal porosity values for all rhizomes used in our experiments are 27-30 %. These data indicate that aerenchyma comprise 21-40 percent of the total rhizome cross sectional area, providing a ventilation system capable of transporting photosynthetically-produced oxygen from the shoots to the rhizomes and roots.

The effective diffusion coefficient (D_s), the exchange coefficient (K_L), and tortuosity (0) have been defined above. We have also separated the total tortuosity of the diffusion path in component tortuosities of the upper shoot and leaves, shoot bases, and rhizomes.

Plant source, or population, had statistically significant effects on all of the diffusive flux model parameters used as dependent variables in one-way analysis of variance (Table 1). The strength of the statistical relationship between plant source population and most model parameters was greater for shoot base and rhizome fluxes than for whole-shoot fluxes but lower than for rhizome-only fluxes. No significant differences between apical and mature rhizome segments were observed for any model parameters. Significant statistical effects of plant vigor (disease status) were noted only rhizome-only flux measurements,

and only for two model parameters- effective diffusion coefficient and the component tortuosity.

In whole-shoot flux measurements, *Thalassia* from Lassing Park in Tampa Bay had generally lower values for D_s and K_L , as well as higher tortuosity values, than Florida Bay *Thalassia* (Table 2). In shoot base and rhizome-only flux measurements, model parameters for Lassing Park and Sunset Cove plants were similar, while Johnson Key plants had significantly high component tortuosity and significantly lower D_s and K_L values. Because Johnson Key rhizomes have higher porosities than Lassing Park and Sunset Cove plants, we would expect lower tortuosity and higher conductance in Johnson Key plants. Apparently, the conductance of rhizomes and shoots depends on more than porosity alone. Anatomical comparisons of rhizomes might show differences in the abundance and resistance of aerenchyma cross-walls or septae.

Plant vigor had statistically significant effects on all flux model parameters, but only for rhizome-only flux measurements (Table 3). Tortuosity and conductance values for healthy *Thalassia* and *Thalassia* with lesions were very similar for whole shoot measurements and shoot base flux measurements. As noted for comparisons of source population characteristics, *Thalassia* with lesions had higher rhizome porosity than healthy plants, but healthy plants had higher conductance (D_s and K_L) values. Unlike the results of the source population comparisons, sick *Thalassia* rhizomes with high porosity had lower tortuosity values than healthy rhizomes with lower porosity.

CONCLUSIONS-Task 2.1

The negative, and curvilinear relationship of whole-plant tortuosity to two-sided leaf surface area (Figure 15) suggests that shoot maturity affects the ability of *Thalassia* shoots to provide oxygen to rhizome tissue. For shoots with more than 75 cm² leaf area, changes in whole-plant tortuosity are negligible, perhaps as the result of rapid, lysigenous development of aerenchyma. Internal resistance of larger shoots is probably offset by the effect of a greater surface area for exchange with the overlying water.

We have continued developing the oxygen flux model given the tortuosity and conductance parameters determined empirically in these experiments (Figure 16). These models provide confirmation of field data gathered in 1988 and 1989 which showed a significant relationship between late-night water column dissolved oxygen concentrations and rhizome oxygen concentrations. Using the data from Figure 15 and a rhizome respiration rate of 0.01 umoles/g dry weight/hr at 25 °C, we calculate that a water column oxygen concentration of 6 ppm will support rhizome respiration rates up to 4 cm from any shoot. At 2.0 ppm dissolved oxygen concentration, diffusion of water column oxygen may provide approximately 30% of respiratory oxygen needs in the same rhizomes.

These experiments demonstrate that the greatest barrier to gas exchange between above-ground and below-ground *Thalassia* tissue is the stem base. While component tortuosities for upper shoots range from 4 to 6, shoot base values range from 20 to 40. However, the high tortuosity of shoot bases is offset by their short length. Rhizomes other than those from Johnson Key Basin, on the other hand, typically have tortuosities close to 1. Higher rhizome and shoot base tortuosities in Johnson Key Basin seem to be particularly maladaptive, given the high porewater sulfide concentrations in Johnson Key Basin sediments.

In summary, we have empirically determined the rates of diffusive gas flux through *Thalassia testudinum* plants and have estimated parameters for inclusion in oxygen models for healthy and diseased seagrass beds. Preliminary comparison of healthy and sick *Thalassia* indicates that higher porosity in sick *Thalassia* rhizomes is offset by lower conductance values. As a result, sick *Thalassia* may be less able to supply oxygen to their belowground tissue, and this deficiency may contribute to the die-back phenomenon.

SUBTASK 2.2. FIELD MEASUREMENT OF THE SUSCEPTIBILITY OF Thalassia AND Halodule TO SULFIDE TOXICITY.

In this task, we have measured survival and growth of Thalassia seedlings and mature shoots in die-back patches using natural and amended sediments. Thalassia seedlings collected in Florida Bay and along Atlantic beaches during August 1990 were grown in a culture system at the Florida Institute of Oceanography field station at Long Key. In March 1991, we transplanted Thalassia seedlings into pots containing builder's sand or natural sediment at four previously-studied sites: Whipray Basin, Rankin Lake, Northeast Johnson Key Basin, and Johnson Key Basin near Johnson Key. In April 1991, we transplanted apical rhizome segments with at least three emergent shoots into trays containing builder's sand or natural sediments at the same four sites. Donor material for the rhizome transplants came from the northwest side of Man O'War Key in Johnson Key Basin. The proximal, cut ends of the rhizomes were capped with rubber serum caps to reduce transplant shock.

RESULTS

Despite our attempts to stabilize our transplant pots and trays, large fish (presumably toadfish, *Opsanus* spp.) repeatedly knocked over our plants in Johnson Key Basin. While physical disturbance was less of a problem in Whipray Basin and Rankin Lake, sediment resuspension rapidly added natural sediment to all of our pots and trays. As a result, some of our transplant mortality should probably be attributed to physical disturbance.

Of 78 seedlings and 52 rhizomes planted in March and April, respectively, 6 seedlings (7.6%) and 20 rhizomes (38%) survived through the summer (Table 4). While the low numbers of survivors preclude statistical examination of treatment effects, a few generalizations can be made. Survival was lowest in Rankin Lake-0% seedlings and 8% rhizomes. Survival was highest in Johnson Key Basin, and intermediate in Whipray Basin.

CONCLUSIONS

No conclusions regarding sediment characteristics can be made from the low numbers of surviving individuals. We can generally conclude that, despite the passage of time since the major die-back episodes in Rankin Lake, the area is still extremely stressful for transplanted *Thalassia*. While seedlings showed poor survival in Whipray Basin, rhizomes did quite well. Overall poor survival of transplant material indicates that *Thalassia* does not have the vigor of a pioneer species like *Halodule*. Rather, as a climax species, it is much more easily disrupted.

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FIGURE 1. Seasonal changes in area for original die-back map patch in Johnson Key basin.

FIGURE 2. Seasonal changes in area for two die-back patches in Johnson Key basin (JKA and JKB) and one die-back patch in Rabbit Key basin.

FIGURE 3. Seasonal changes in areal extent of a Thalassia map patch within a die-back area in Sunset Cove.

FIGURE 4. Seasonal changes in Thalassia cover in photoquads located along the ecotone of a die-back patch in Johnson Key basin and along the ecotone of a Thalassia patch in Sunset Cove.

FIGURE 5. Braun Blanquet frequency, abundance, and density data for Rankin Lake and Johnson and Rabbit Key basins during February 1991.

FIGURE 6. Braun Blanquet frequency, abundance, and density data for Rankin Lake and Johnson and Rabbit Key basins during April 1991.

FIGURE 7. Braun Blanquet frequency, abundance, and density data for Rankin Lake and Johnson and Rabbit Key basins during June 1991.

FIGURE 8. Braun Blanquet frequency, abundance, and density data for Rankin Lake and Johnson and Rabbit Key basins during August 1991.

FIGURE 9. Braun Blanquet frequency, abundance, and density data for Rankin Lake and Johnson and Rabbit Key basins during October 1991.

FIGURE 10. A summary of the seasonal changes in Braun Blanquet frequency, abundance, and density data for Thalassia testudinum and Halodule wrightii in Rankin Lake and Johnson and Rabbit Key basins during 1991.

FIGURE 11. Water temperature and salinity data for Rankin Lake and Johnson and Rabbit Key basins.

FIGURE 12. Time course of tracer flux through healthy and diseased Thalassia testudinum from Florida Bay. A. Whole shoot flux, B. Fluxes through shoot base and rhizome, and C. Fluxes through rhizome only.

FIGURE 13. A. Cross section of Thalassia testudinum rhizome showing aerenchyma as open spaces. B. Computer enhanced image.

FIGURE 14. Frequency distribution of rhizome porosity.

FIGURE 15. Rhizome tortuosity versus two-sided leaf surface area.

FIGURE 16. Output from a whole shoot flux model. Oxygen flux as a function of rhizome length.

DIE-BACK PATCH AREA

Johnson Key

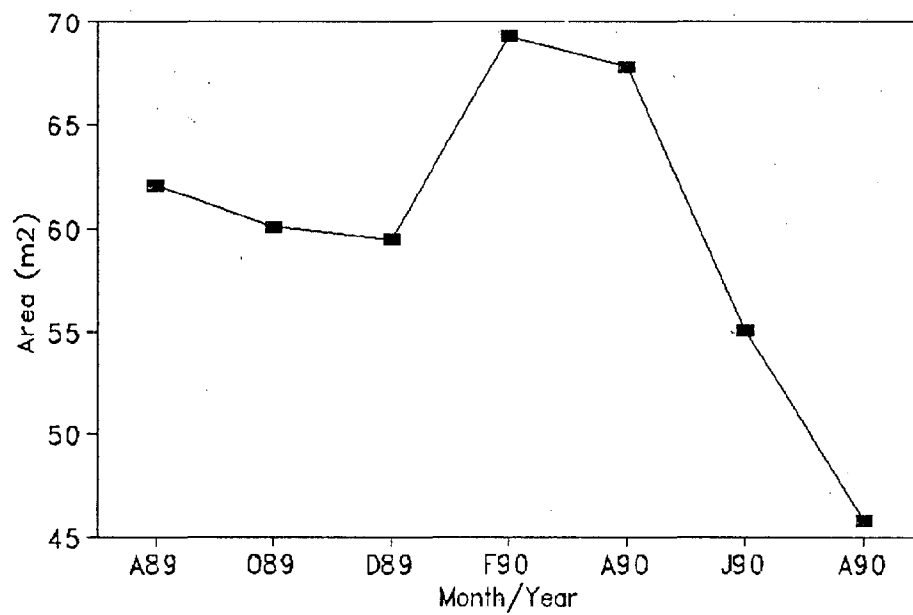


FIGURE 1. Seasonal changes in area for original die-back map patch in Johnson Key basin.

DIE-BACK PATCH AREA

Johnson and Rabbit Keys 1991

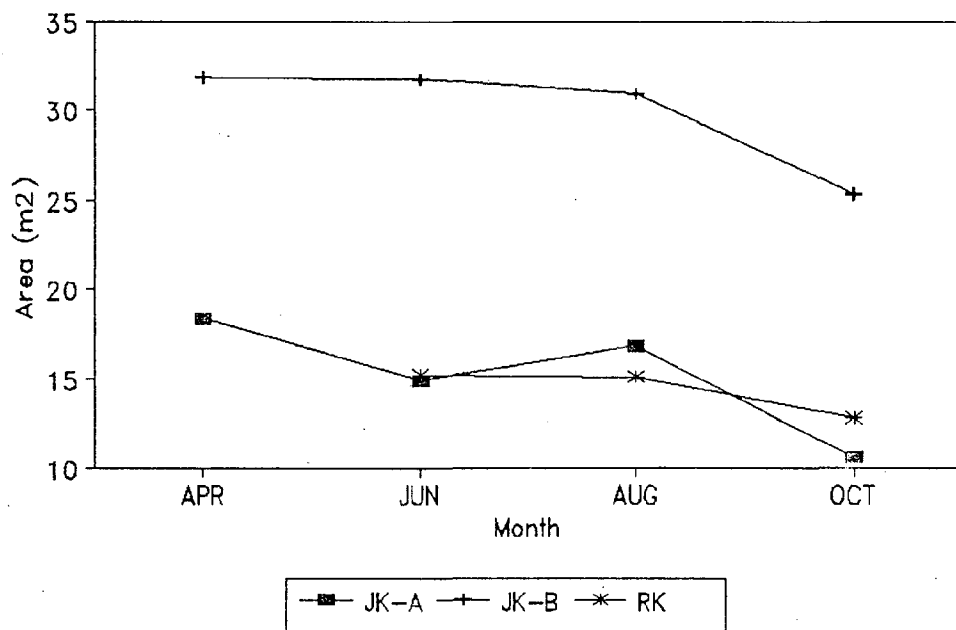


FIGURE 2. Seasonal changes in area for two die-back patches in Johnson Key basin (JKA and JKB) and one die-back patch in Rabbit Key basin.

THALASSIA PATCH AREA

Sunset Cove 1991

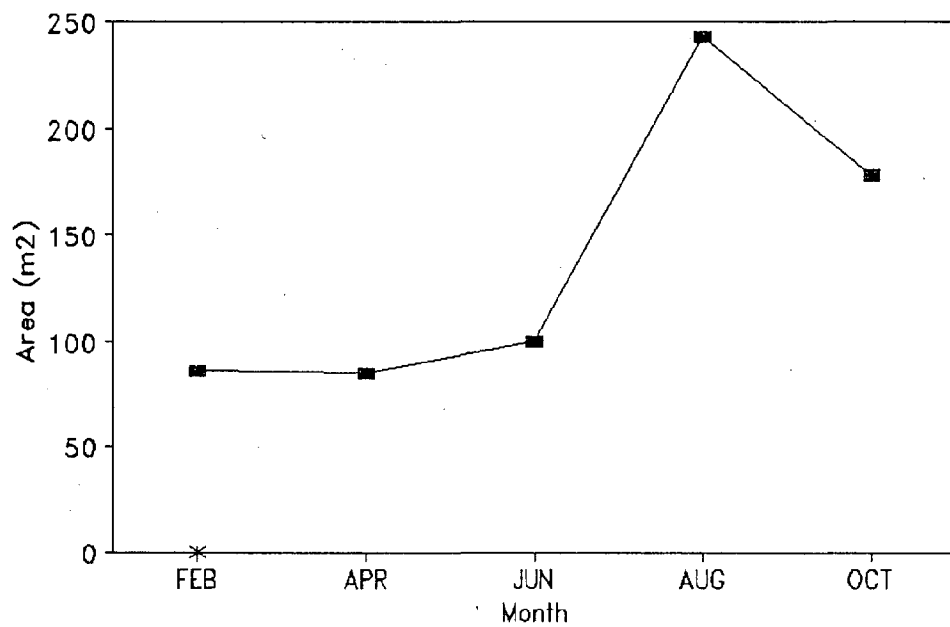


FIGURE 3. Seasonal changes in areal extent of a Thalassia map patch within a die-back area in Sunset Cove.

PHOTOQUAD DATA Florida Bay

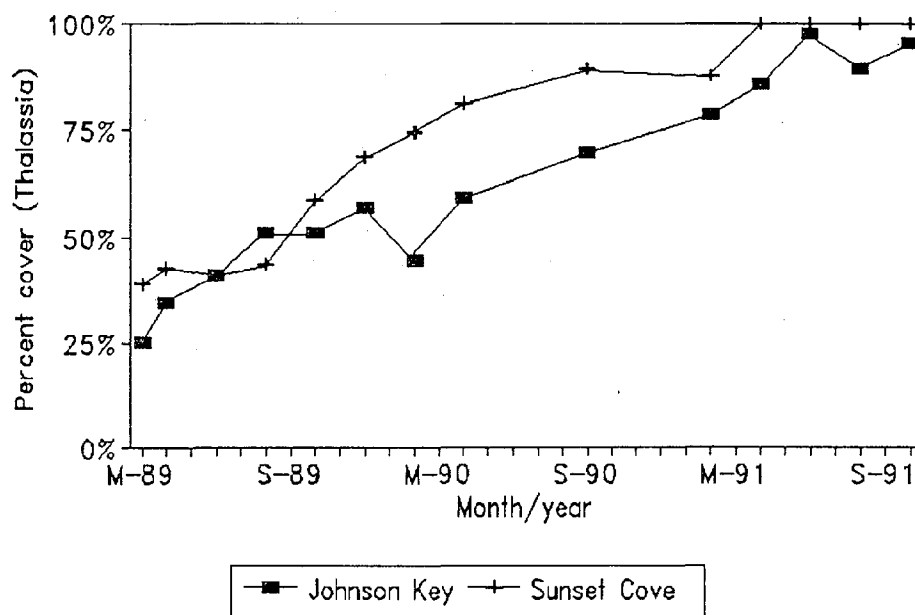


FIGURE 4. Seasonal changes in *Thalassia* cover in photoquads located along the ecotone of a die-back patch in Johnson Key basin and along the ecotone of a *Thalassia* patch in Sunset Cove.

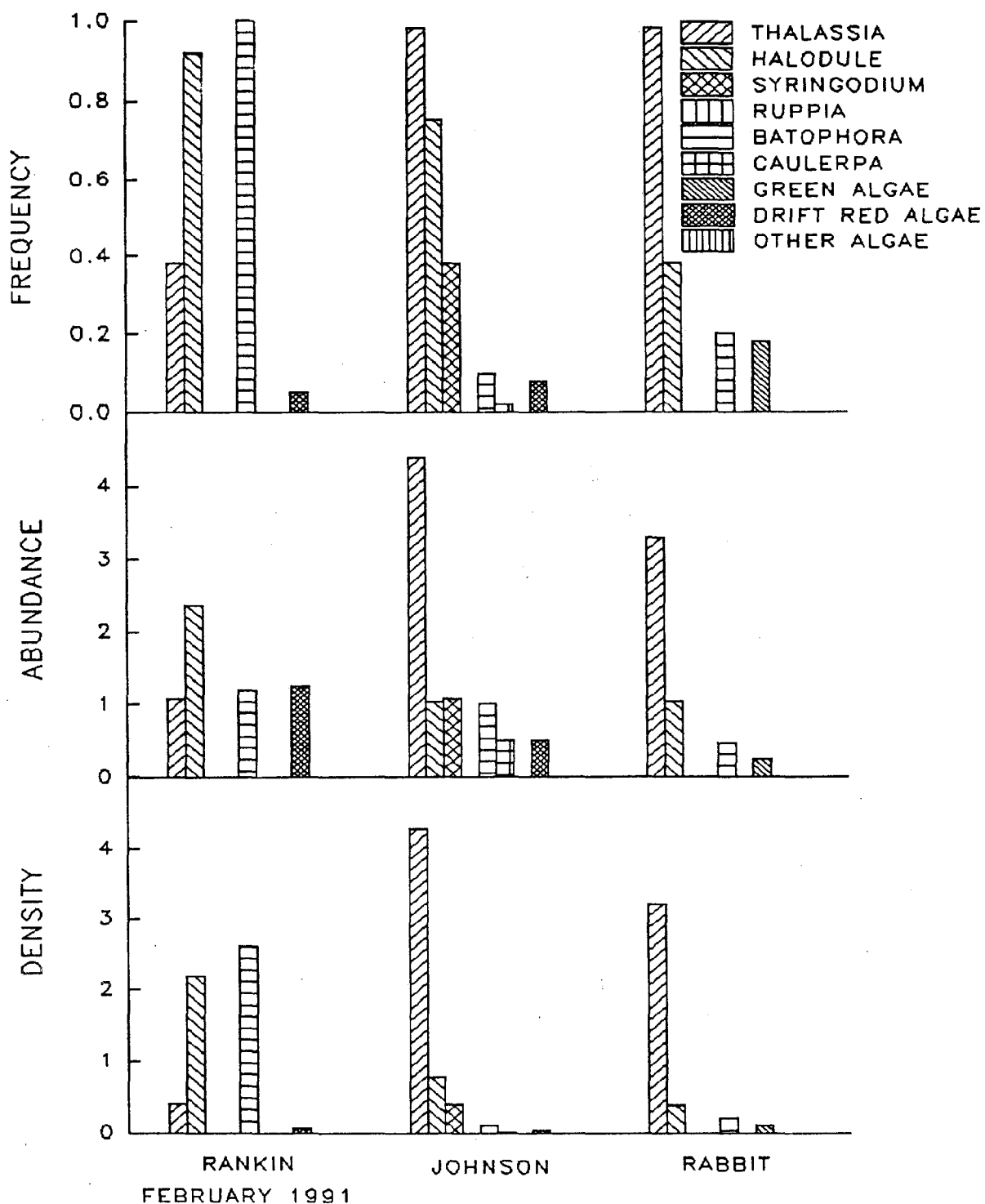


FIGURE 5. Braun Blanquet frequency, abundance, and density data for Rankin Lake and Johnson and Rabbit Key basins during February 1991.

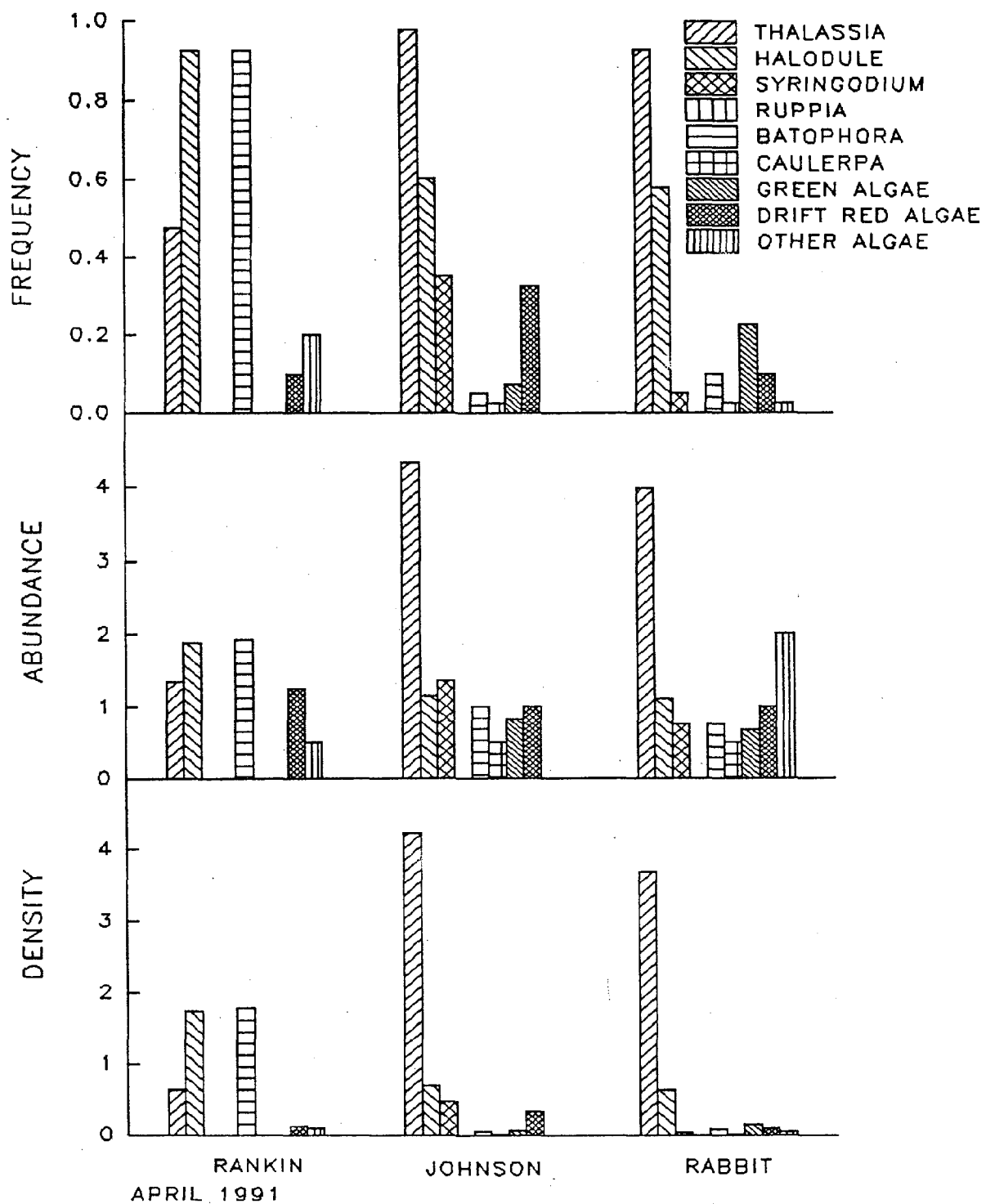


FIGURE 6. Braun-Blanquet frequency, abundance, and density data for Rankin Lake and Johnson and Rabbit Key basins during April 1991.

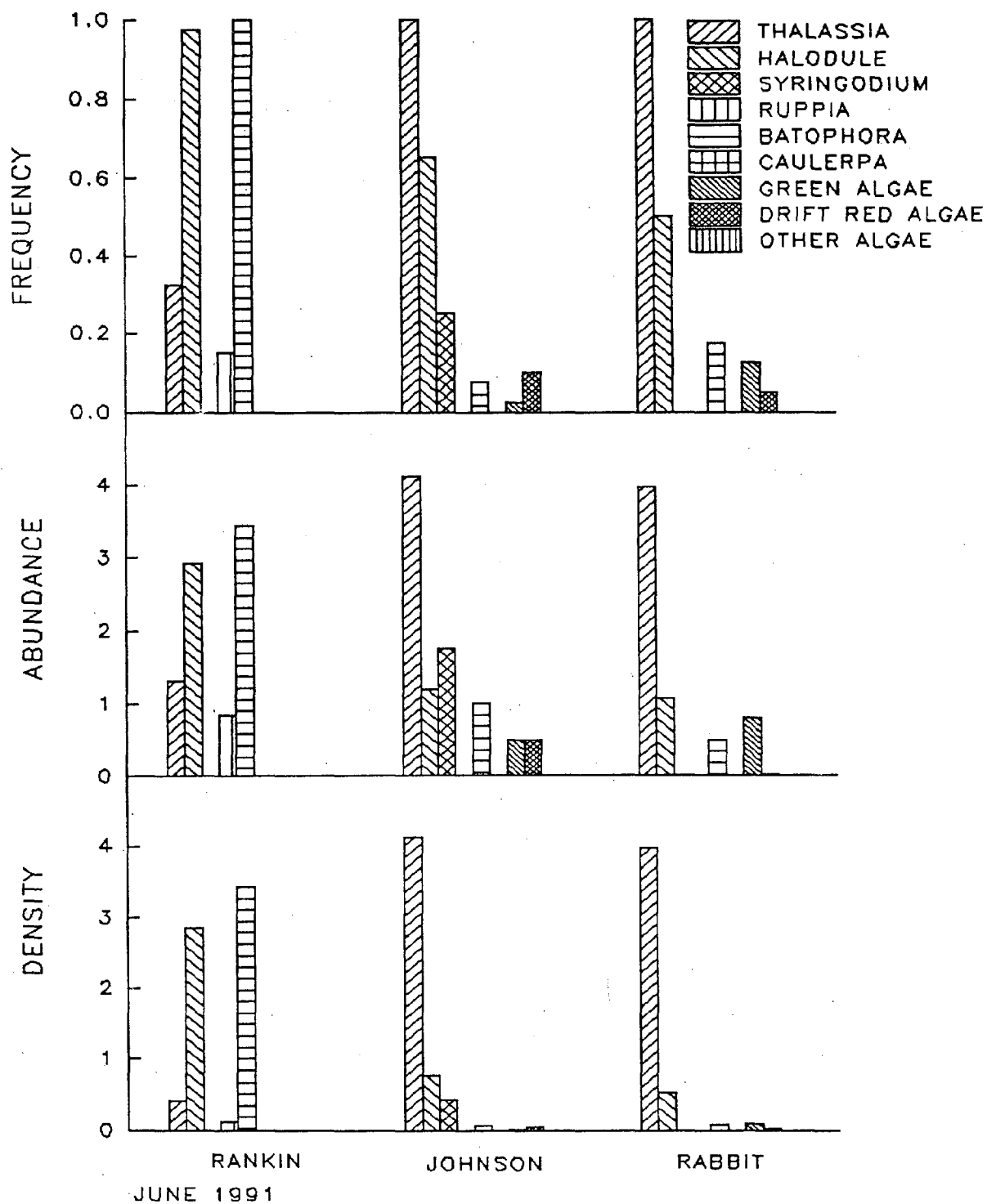


FIGURE 7. Braun Blanquet frequency, abundance, and density data for Rankin Lake and Johnson and Rabbit Key basins during June 1991.

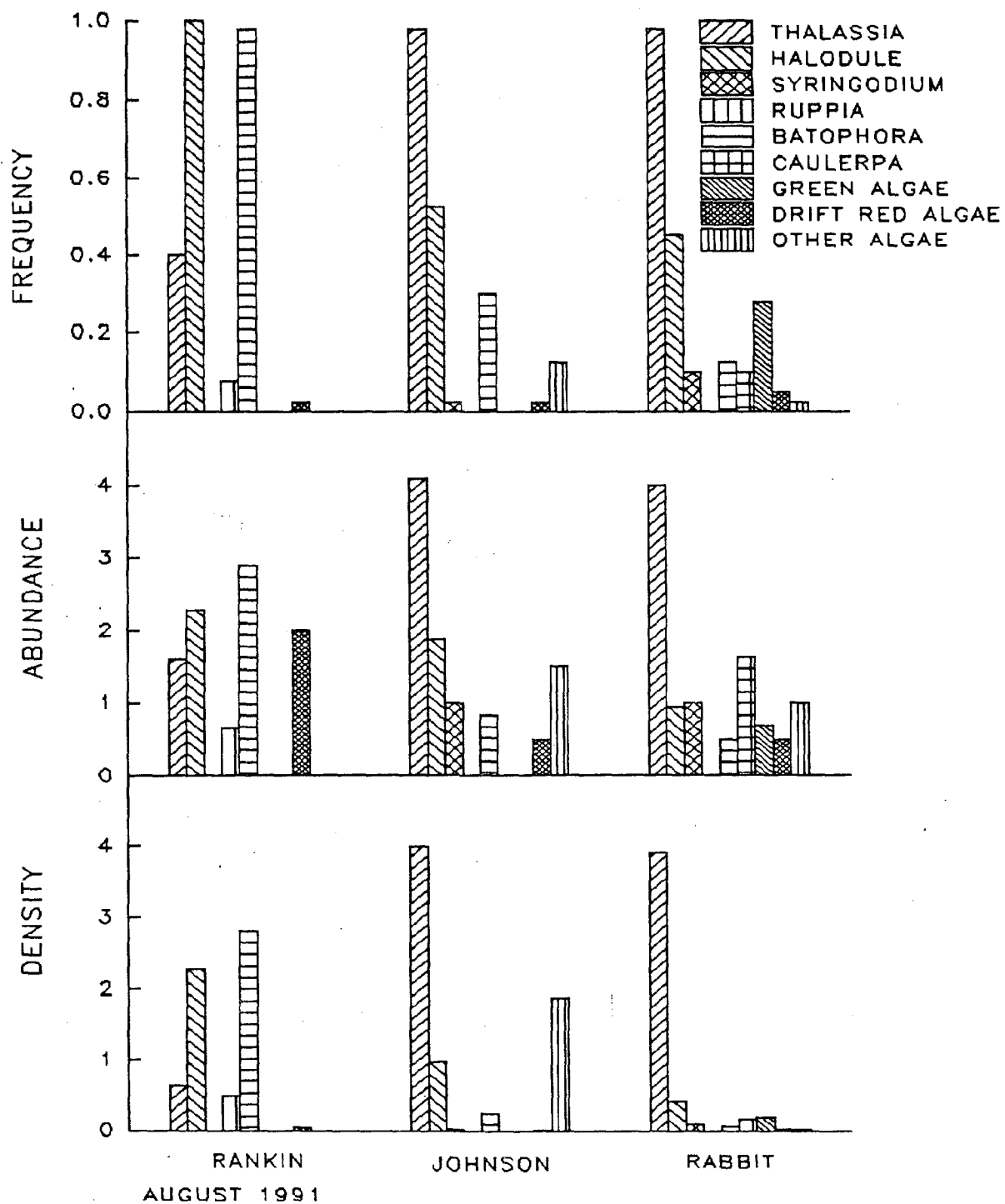


FIGURE 8. Braun Blanquet frequency, abundance, and density data for Rankin Lake and Johnson and Rabbit Key basins during August 1991.

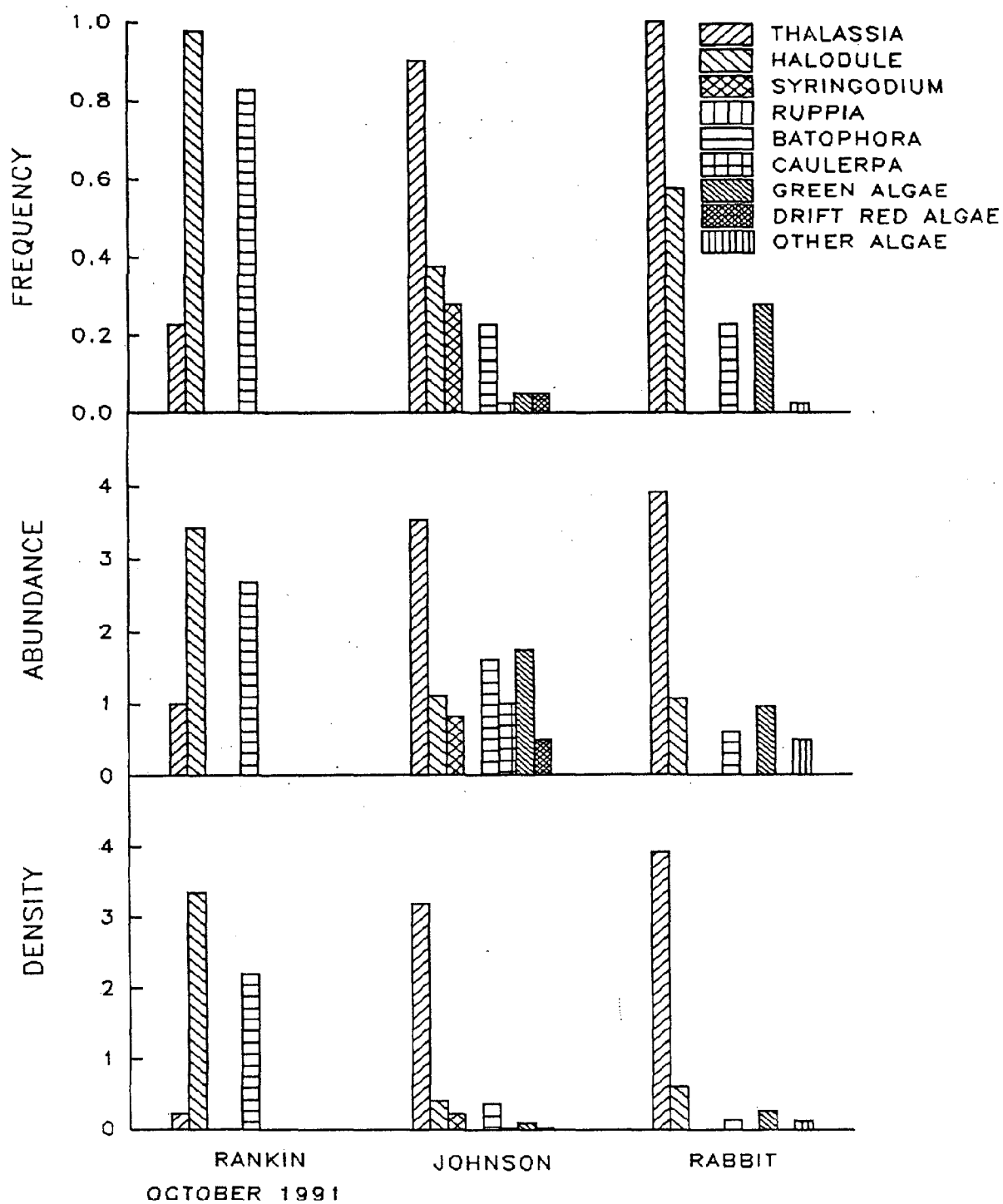


FIGURE 9. Braun Blanquet frequency, abundance, and density data for Rankin Lake and Johnson and Rabbit Key basins during October 1991.

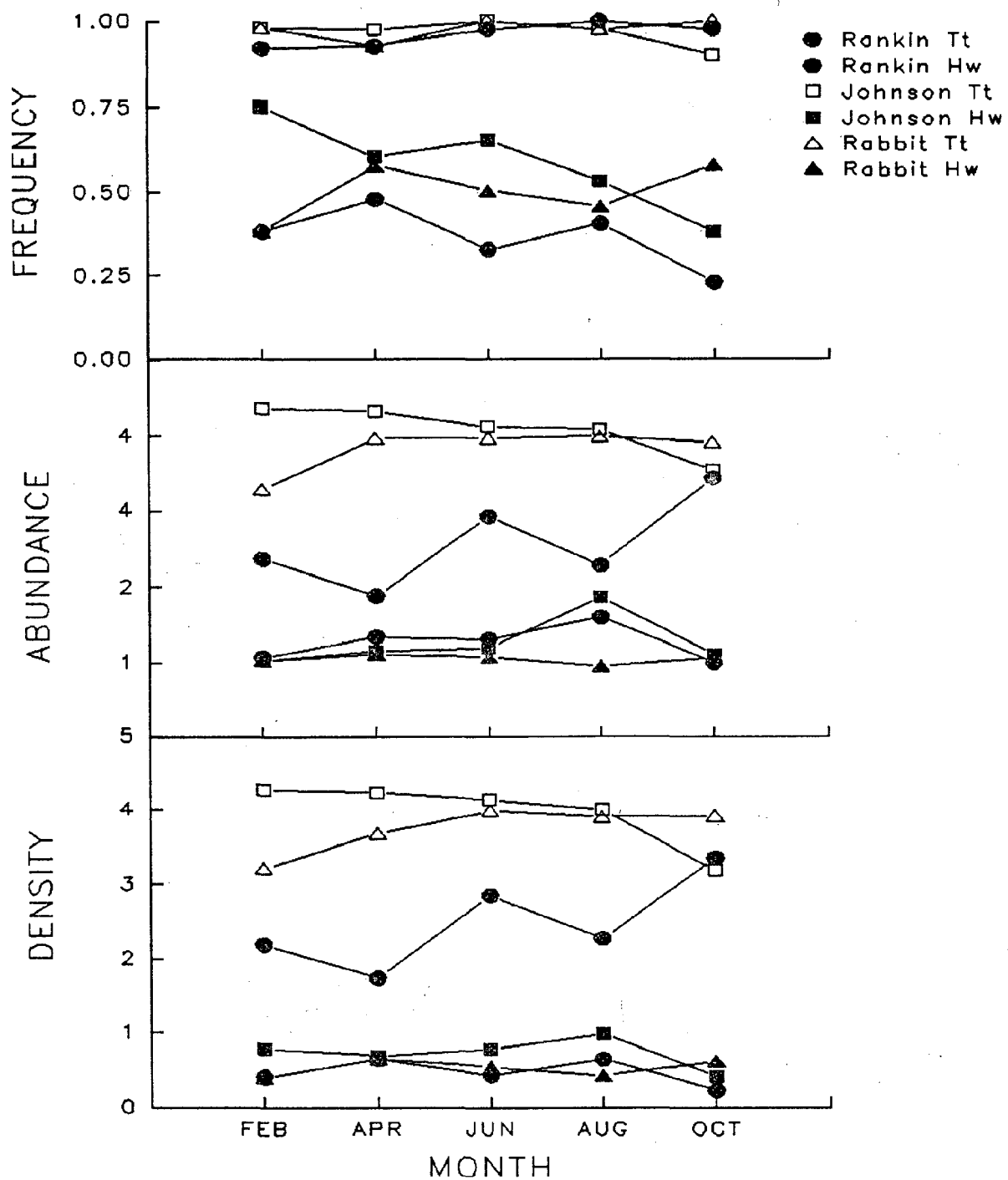


FIGURE 10. A summary of the seasonal changes in Braun Blanquet frequency, abundance, and density data for Thalassia testudinum and Halodule wrightii in Rankin Lake and Johnson and Rabbit Key basins during 1991.

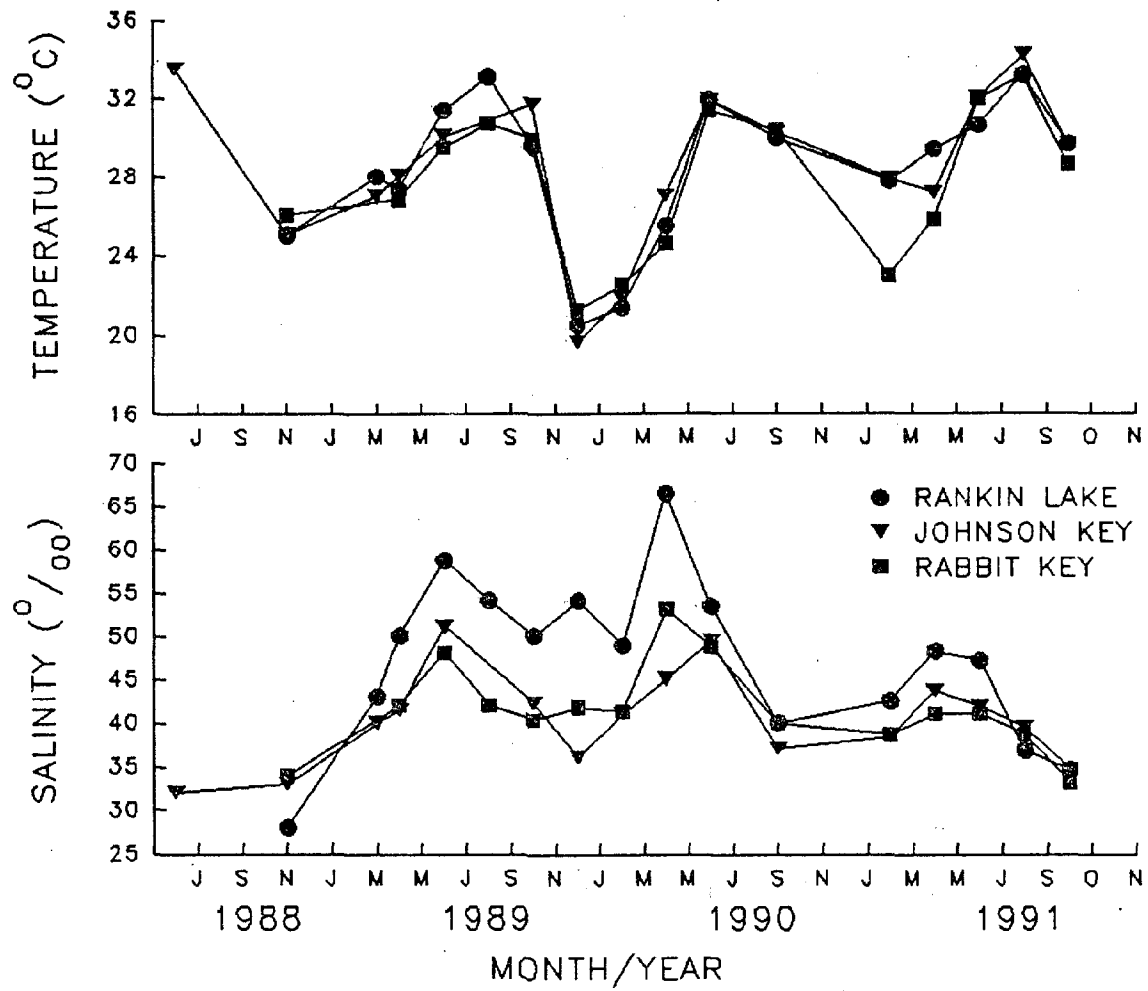
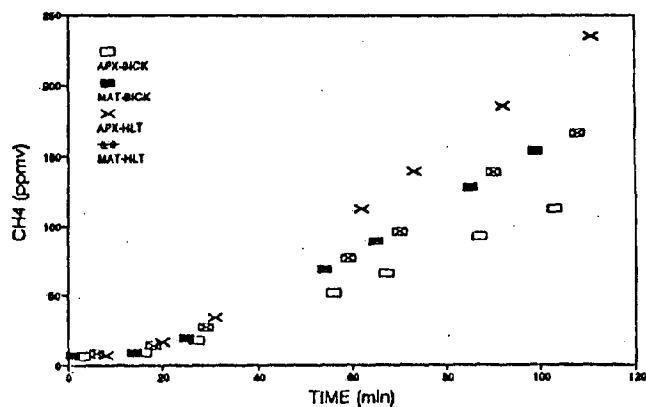


FIGURE 11. Water temperature and salinity data for Rankin Lake and Johnson and Rabbit Key basins.

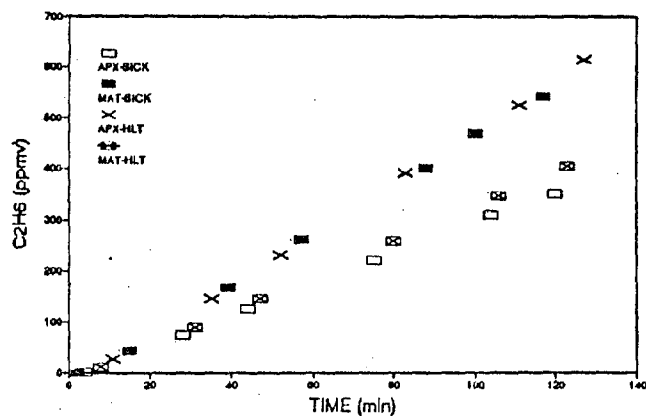
PLAFLEX #10A - 12/11/91
WHOLE SHOOT FLUX

A



PLAFLEX #10A - 12/11/91
NO SHOOT FLUX

B



PLAFLEX #10A - 12/11/91
RHIZOME FLUX

C

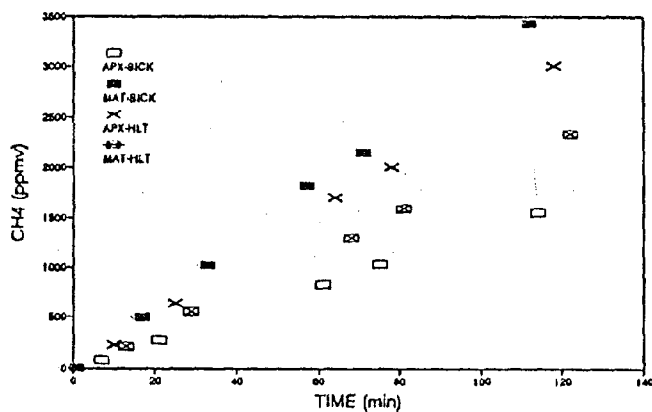
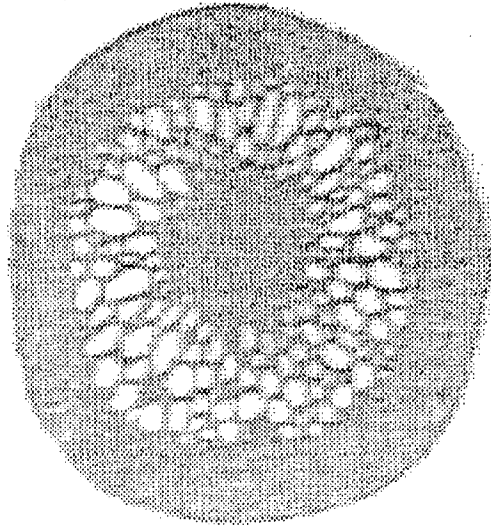


FIGURE 12. Time course of tracer flux through healthy and diseased *Thalassia testudinum* from Florida Bay. A. Whole shoot flux, B. Fluxes through shoot base and rhizome, and C. Fluxes through rhizome only.

A



B

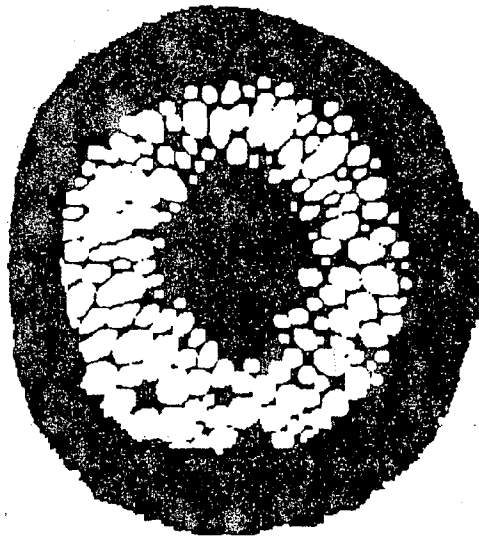


FIGURE 13. A. Cross section of Thalassia testudinum rhizome showing aerenchyma as open spaces. B. Computer enhanced image.

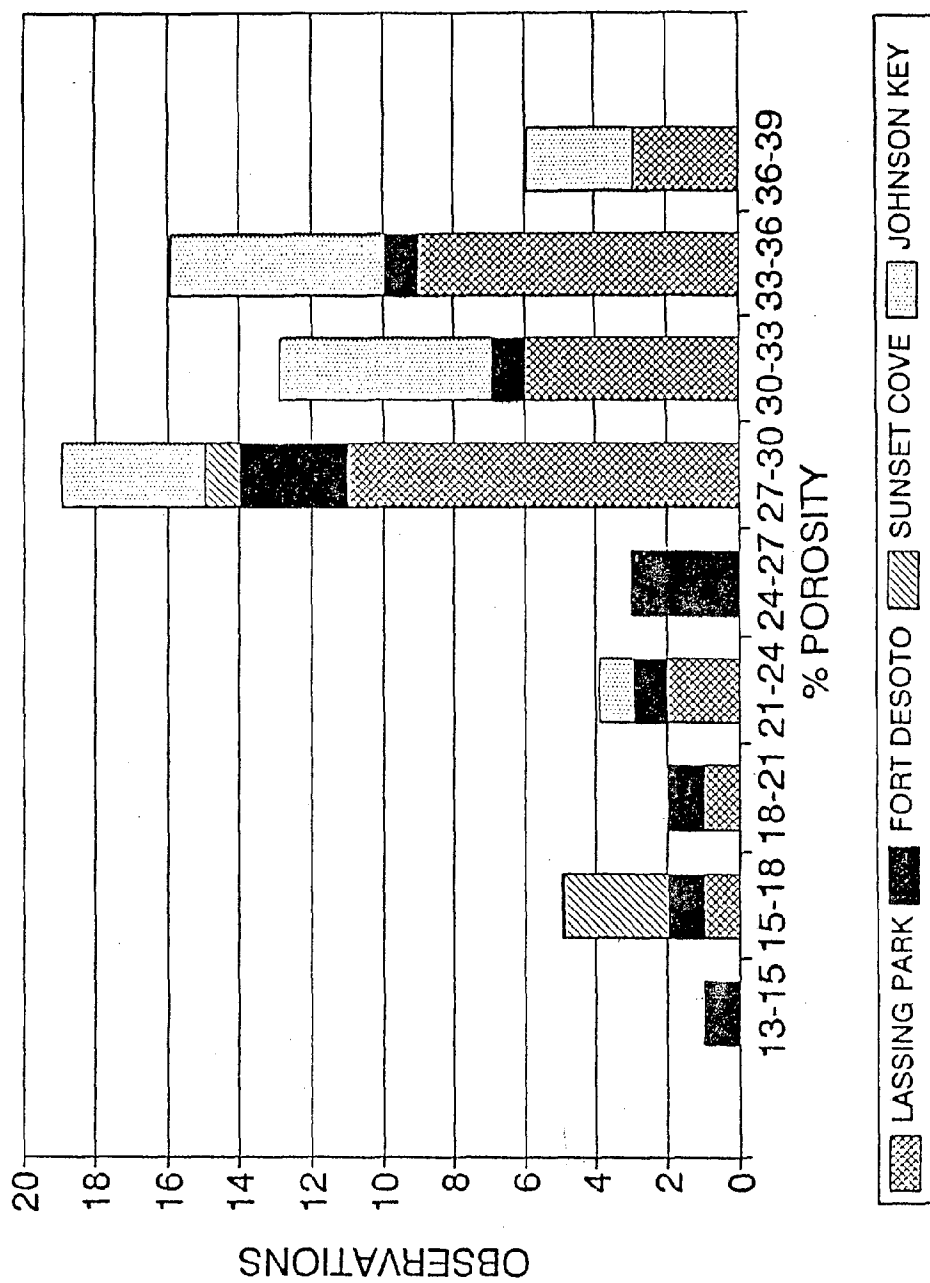


FIGURE 14. Frequency distribution of rhizome porosity.

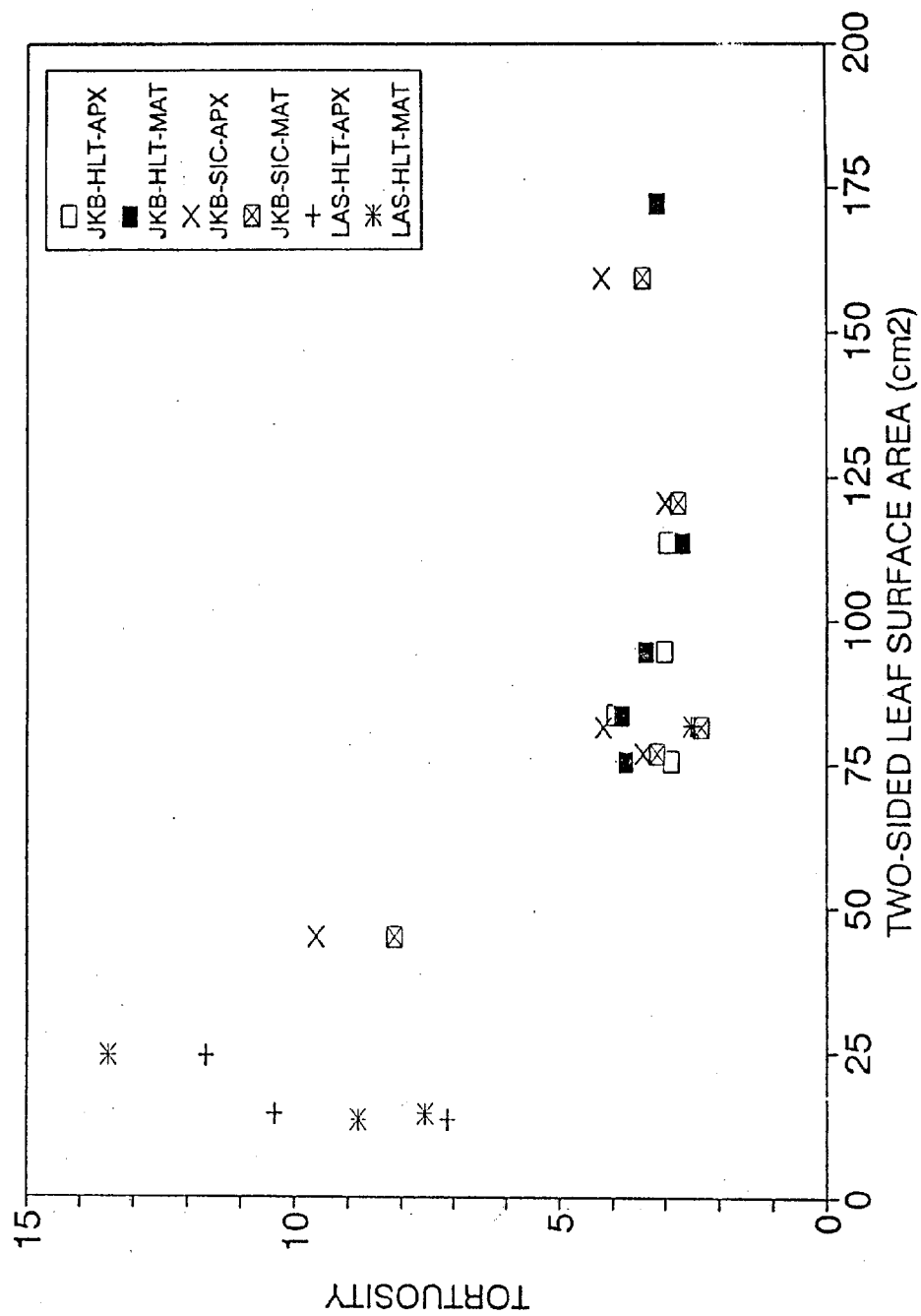


FIGURE 15. Rhizome tortuosity versus two-sided leaf surface area.

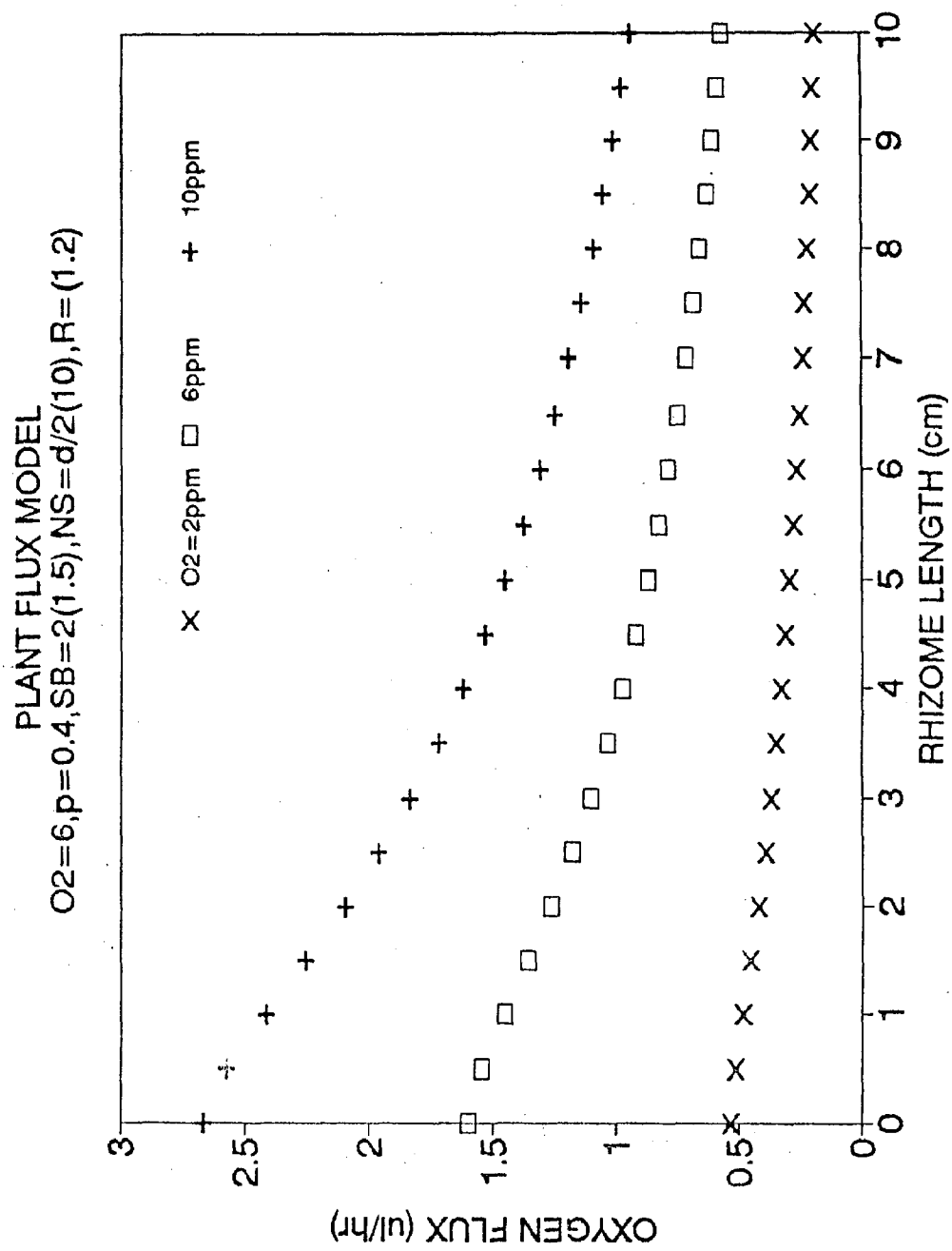


FIGURE 16. Output from a whole shoot flux model. Oxygen flux as a function of rhizome length.

TABLE 1: EFFECTS OF PLANT SOURCE, VIGOR, AND RHIZOME TISSUE TYPE ON RHIZOME POROSITY AND GAS CONDUCTANCE. Data are F-Ratios of one-way analyses of variance. See methods for definitions of gas conductance dependent variables.

Independent Variables	df	Rhizome Porosity	Dependent Variables			
			D _s	K _L	Aggregate Tortuosity	Component Tortuosity
A. Whole-Shoot Gas Fluxes						
Plant Source	2	---	4.29*	5.04*	8.97***	4.00*
Plant Vigor	1	---	0.34	0.15	0.46	0.85
Rhizome Tissue	1	---	0.05	0.08	0.03	0.03
B. Shoot Base and Rhizome Fluxes (No Shoot)						
Plant Source	2	---	11.75***	12.44***	6.66**	6.55**
Plant Vigor	1	---	1.57	0.09	2.49	2.00
Rhizome Tissue	1	---	1.61	3.10	0.31	2.78
C. Rhizome Fluxes (Shoots and Shoot Bases Removed)						
Plant Source	2	32.12***	18.67***	6.66**	---	19.59***
Plant Vigor	1	1.62	6.84*	1.50	---	9.45**
Rhizome Tissue	1	0.27	0.24	0.08	---	0.54

* P= 0.05; ** P= 0.01; *** P=0.001

TABLE 2: EFFECTS OF PLANT SOURCE ON RHIZOME POROSITY AND GAS CONDUCTANCE. Data are mean values of dependent variables. Values of the same variable with the same letter subscript are not significantly different according to Duncan's multiple range test. See methods for definitions of gas conductance model parameters. K_L values are multiplied by 1000 for presentation.

Plant Source	Flux Model Parameters			
	Rhizome Porosity	D_s	K_L	Aggregate Component Tortuosity
A. Whole-Shoot Gas Fluxes				
Lassing Park- Tampa Bay	---	0.011 b	0.78 b	8.00 a
Sunset Cove- Florida Bay	---	0.033 a	2.22 a	2.90 b
Johnson Key- Florida Bay	---	0.020 ab	1.29 b	3.86 b
B. Shoot Base and Rhizome Fluxes (No Shoot)				
Lassing Park- Tampa Bay	---	0.064 a	10.5 a	1.77 b
Sunset Cove- Florida Bay	---	0.064 a	10.2 a	1.76 b
Johnson Key- Florida Bay	---	0.034 b	4.5 b	2.47 a
C. Rhizome Fluxes (Shoots and Shoot Bases Removed)				
Lassing Park- Tampa Bay	0.19 b	0.180 a	31.1 a	---
Sunset Cove- Florida Bay	0.20 b	0.170 a	28.3 a	---
Johnson Key- Florida Bay	0.32 a	0.120 b	18.5 b	---

TABLE 3: EFFECTS OF PLANT VIGOR ON RHIZOME POROSITY AND GAS CONDUCTANCE. Data are mean values of dependent variables. Values of the same variable with the same letter subscript are not significantly different according to Duncan's multiple range test. See methods for definitions of gas conductance model parameters. K_L values are multiplied by 1000 for presentation.

Plant Vigor	Flux Model Parameters			
	Rhizome Porosity	D_s	K_L	Aggregate Tortuosity Component Tortuosity
A. Whole-Shoot Gas Fluxes				
Healthy <i>Thalassia</i>	---	0.017 a	1.21 a	5.21 a 5.17 a
<i>Thalassia</i> with lesions	---	0.024 a	1.38 a	4.04 a 4.91 a
B. Shoot Base and Rhizome Fluxes (No Shoot)				
Healthy <i>Thalassia</i>	---	0.043 a	6.54 a	2.31 a 29.7 a
<i>Thalassia</i> with lesions	---	0.043 a	5.58 a	2.20 a 28.5 a
C. Rhizome Fluxes (Shoots and Shoot Bases Removed)				
Healthy <i>Thalassia</i>	0.27 b	0.148 a	24.1 a	--- 1.25 a
<i>Thalassia</i> with lesions	0.31 a	0.116 b	18.5 b	--- 1.39 b

TABLE 4: SURVIVAL OF SEEDLING AND RHIZOME TRANSPLANTS IN NATURAL AND ARTIFICIAL SEDIMENTS AT FOUR SITES IN FLORIDA BAY.

Site/Sediment	Seedlings		Rhizomes	
	Planted	Survivors	Planted	Survivors
Whipray Basin				
Natural Sediment	12	2	6	2
Sand	12	1	6	4
Rankin Lake				
Natural Sediment	12	0	6	0
Sand	12	0	6	1
Northeast Johnson				
Natural Sediment	12	0	6	3
Sand	12	1	8	5
Johnson Key				
Natural Sediment	--	--	6	1
Sand	6	2	8	4

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